Developing science, technology and innovation indicators: what we can learn from the past

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(January 2007)

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Abstract

The science-technology-innovation system is one that is continuously and rapidly evolving. The dramatic growth over the last twenty years in the use of science, technology and innovation (STI) indicators appears first and foremost the result of a combination between on the one hand the easiness of computerized access to an increasing number of measures of STI and on the other hand the interest in a growing number of public policy and private business circles in such indicators as might be expected in societies which increasingly use organised science and technology to achieve a wide variety of social and economic objectives and in which business competition is increasingly based on innovation. As highlighted on the basis of 40 years of indicators work, frontiers and characteristics that were important last century may well no longer be so relevant today and indeed may even be positively misleading.

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Introduction

Like any other statistic, indicators on science, technology and innovation (STI) can be used and *ab*used. The dramatic growth over the last twenty years in the use of STI indicators appears first and foremost the result of a combination between on the one hand the easiness of computerized access to an increasing number of measures of STI and on the other hand the interest in a growing number of public policy and private business circles in such indicators as might be expected in societies which increasingly use organised science and technology to achieve a wide variety of social and economic objectives and in which business competition is increasingly based on innovation.

Much longer in use already in the science and technology research community, STI indicators have today become an essential ingredient in research on the modes of operation of the science-technology-innovation sub-system itself and its relationship with the wider social system. In societies which allocate large sums from both the public and private sector for such things as (experimental) research and development (R&D), new software tools and programmes as well as other technical support services, the design and development of new products, processes or organisational innovations, it will be inevitable that policy-makers, private businesses, financial investors as well as researchers would wish to have available some quantitative statistical tools to control the scale of commitment and its evolution and to learn more about the effectiveness of these activities. It is also quite natural that they would wish to make comparisons between countries, organisations (public and/or private) and industries in the direction, scale and efficiency of their commitments.

In this sense, the national development of STI statistics from the early National Science Foundation surveys in the US in the fifties to the most recent publication at the time of writing of this paper on Canada's strength in science and technology by the Committee on the State of Science & Technology in Canada (2006) fits the natural desire to measure national STI investments and their possible impact on economic performance. However, the measurement of STI is not an easy matter. Even simply to record the expenditures on personnel and equipment inputs in the R&D process is by no means as easy as it may appear at first sight and international comparisons are attended by numerous problems, as forty years of painstaking OECD harmonisation work is witness to. The measurement of the outputs of the system is even more difficult and will always remain controversial.

It means that it will always be essential to use STI statistics in full awareness of the "footnote" problems which arise in the differences across countries in definition, classification and measurement of most STI indicators. Otherwise, STI indicators may easily be abused. And whereas in the world of economic statistics abuse often meets its ghost – admittedly often only years later – in the world of STI statistics the possibilities for abuse given the often endogenous impact of such statistics on public S&T spending itself, are more numerous and much more oblivious. This holds not only for STI performance assessment at the level of individuals or organisations, but also at the level of countries. One might e.g. remember how the comparisons made in the 70's and 80's between the so-called socialist economies and the OECD countries ignored many of the substantial differences in definitions between R&D in the West and in the East. Today, it could be argued that there are similar major problems in making comparisons between the developed, emerging and other developing countries in comparing STI indicators.

Given our combined average age of 70, we thought it might be useful to reflect upon the development and use of STI and R&D in particular over the last forty years, before concluding with some of the more recent challenges to STI indicators. After all, R&D has by now become not just one of the most well-known acronyms amongst S&T policy makers and researchers, it has actually achieved "general purpose" fame, both as policy target – one may think of the EU's so-called 3% Barcelona target – and as object of economic analysis.

Section 1. On economic (mis-)measurement : «*plus ça change, plus c'est la même chose*»

Obviously problems of definition and measurement are not unique to the science and technology system. Some ten years ago, one of us at a meeting celebrating the fiftieth anniversary of ISTAT, the Italian statistical agency, wrote the following. "Economics has sometimes been called by other social scientists the "queen" of social sciences because of economists' superior ability to measure and quantify the main variables of economic activity. Indeed, the motto of the econometrics society "*science is measurement*" could be said to characterize the ascent of at least that part of the economics profession this Century to the more applied sciences. The superior ability of economists to measure, for example, a number of key aggregate variables (growth, labour force, unemployment, productivity, inflation) has led to widespread policy acceptance of such concepts during the post-war period. At the same time, new concepts (total factor productivity, the "NAIRU", long term unemployment as well as a range of alternative monetary variables) have been quickly developed and integrated into policy research, often without the interminable conceptual debates so typical of the other social sciences. Finally, it could be argued that with the end of the cold war and the demise of the socialist, planned economic model, alternative economic concepts have now also disappeared from the international statistical yearbooks. The final supremacy of the market model therefore appears to some extent reflected in the complete policy convergence of harmonized aggregate economic concepts and measures. All this benefits the growing number of users of such statistics; no longer confined to central government and planning agencies or university research institutes, but including now also many private financial institutions, consulting and advisory firms and other organisations and individuals...". However, as was also noted: "…users and above all policy makers have gone too far, much too far in their "belief" in the true value of such harmonised aggregate economic concepts and proxies. Increasingly, there is a discrepancy between the total reliance; one could say the "fetishism" of macro-economic policy making for such aggregate economic concepts and the growing mismeasurement of economic production, its rate of growth and "real" improvement in economic welfare." (Soete 1996).

In short even the most basic economic concepts such as GDP, probably the most widely-used economic indicator in the world, are beset with problems in their measurement, especially now that services account for between 60 to 80 per cent of total output in most developed countries, and in making international comparisons amongst countries despite the use of purchasing power parity adjustments[2]. No one really knows how to measure the output of

[2] Whereas the use of such internationally harmonized PPP adjustments has corrected for differences in inflation rates between countries, their use across the board e.g. also for international comparisons of R&D expenditures or other productivity performance measurements raises many questions.. One of the first ever papers written by Soete (1975) was a comment on an OECD proposal for a new method to deflate R&D expenditure (OECD, 1975). Such relatively old questions about misuse of PPP are today exacerbated by new economic discussions (Neary 2004) about intrinsic biases in PPP, likely to overstate the income convergence across poor and rich countries as compared to nominal exchange rates. One major reason for this is that increasingly large quantities of intangible internationally traded goods are available across the world at similar prices reflecting intellectual property compensations in poor as well as rich countries. Just to give one example highlighting the underlying

such sectors as health, education, or government services themselves, which account for large fractions of GDP in many countries. In fact **input** measures are often used as a surrogate for **output** measures in these areas. The problems are even greater when it comes to the least developed countries where greater parts of the economy are in subsistence agriculture and household activities where no market transactions are involved. This does not mean that all measures of economic activity are useless but it certainly does mean that they must be used with great care and in full awareness of their limitations and of the stage of evolution of the particular economies and societies which are being considered and compared. A point which is insufficiently recognized in international comparisons as argued below.

The natural sciences too have their problems of measurement, especially for example in areas such as astronomy and geology where large errors have been made in the past. However, progress has been made by devoting continuous attention to the improvement of measurement systems with great success. One may wonder whether the measurement in the social sciences will ever be quite as accurate. In particular, in most social sciences it appears still difficult, to achieve such reliable improvements despite the rapidly growing opportunities for computer-based data collection and behavioural experiments mimicking controlled experiments environments under laboratory conditions. The emergence of strategic behaviour as a result of the policy use of such new measures will, sometimes quickly, undermine the actual measurement value of such indicators. Nevertheless, continuous efforts in improving the measurement of STI are needed.

Section 2: Measuring STI: the early years

The OECD, in close interaction with its members' statistical offices, has of course been particularly influential and constructive over the last 40 years in developing international standards for Research and Development measurement and in stimulating and improving input and output measurement of both R&D and other services. Together with others at the OECD and in particular Yvan Fabian and Alison Young, one of us happened to be part of those early discussions in the 60's on the inclusion or exclusion of particular activities in the Frascati Manual (1981) (Freeman 1962, Fabian 1963, Freeman and Young 1965, Freeman 1967, Freeman 1969). It appeared particularly difficult to separate research and experimental development activities from the broader spectrum of scientific and technological services (STS) concerned with providing support for R&D, disseminating the results, applying new knowledge in various ways and producing and selling new products. Not surprisingly, organisations which were engaged in research and experimental development were often also engaged in such STS activities as well. The Frascati Manual tried to distinguish between research and experimental development and related scientific activities. Among the latter would be specified such activities as general scientific library, information and documentation services; training and education of research workers in specialised educational institutions such as universities; general purpose data collection, for example routine geological and geophysical survey work, mapping and exploration activities, routine oceanographic survey work, daily meteorological records, monthly production statistics, collection and arrangement of specimens for museums, zoological and botanical gardens; routine testing and standardisation activities and also design and engineering activities.

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problem: it is estimated that it would cost today around $ 4000 to produce a car in China; however with correct payment of all intellectual property compensations this figure would double to between $ 7000 and $ 8000.

The main theoretical criterion for the Frascati scheme of separation of the R&D function from related scientific activities was the distinction between **novelty** and **routine**:
"*In so far as the activity follows an established routine pattern it is not R&D. In so far as it departs from routine and breaks new ground, it qualifies as R&D. Thus, for example, the collection of daily routine statistics on temperature or atmospheric pressure is not R&D, but the investigation of new methods of measuring temperature or the investigation of temperatures under circumstances in which they have never been previously recorded (for example, outer space or the interior of the earth)* ***is*** *research. Likewise, the publication of a book which simply records daily information on the temperature or pressure is not R&D, but general purpose data collection. The systematic analysis of these recordings with a view to explaining long-term changes in climate, or the possible effects of changes in ocean currents,* ***is*** *research activity. To take another example: in the field of medicine, routine general autopsy on the causes of death is* ***not*** *research, but special investigation of a particular mortality in order to establish the side effects of certain forms of cancer treatments* ***is*** *research. Routine tests on patients, carried out for doctors, as for example, blood tests and bacteriological tests, are* ***not*** *research. But a special programme of blood tests in connection with the introduction of a new drug* ***is*** *research.*" On the basis of this criterion most of the activities of central government testing and standardisation institutes, major scientific libraries and information services, museums and geological and meteorological survey organisations became **excluded** from research and experimental development as routine related scientific activities. Also excluded were many scientific and technical activities at enterprise level, including consultancy, project feasibility studies, much design and engineering, production engineering and quality control as well as training and information services.

As we discuss below, these factors are relatively important in considering science-technology systems which are either in a process of very rapid growth ("explosion") such as today, the emerging economies or at that time Japan and the European countries witnessing a rapid post-war catching up process of economic growth or; science and technology systems in a process of rapid contraction ("implosion"). In the case of "exploding" systems, whilst almost all STS are expanding there is an increasing concentration on R&D and some re-classification of STS activities in this direction. R&D expenditures typically increase much more rapidly than personnel. On the other hand, in the case of "imploding" science-technology systems, as was the case after the collapse of the Soviet Union and the end of the centrally planned economies in Eastern Europe, a process of involuntary under-development of R&D activities was set in motion. In all those countries, there was been an abrupt fall in R&D activities in the 1990s, sometimes by more than 50 per cent. However, the fall in expenditure was much greater than the fall in personnel and according to many descriptive accounts, many of those employed in what were once (and sometimes still are) Research Institutes or R&D Departments are now engaged in a variety of other STS, either part-time or full-time, such as consultancy, teaching, computer services, information services, design work or production engineering. Whilst in the short term there may be sound clear-cut gains from this re-deployment and some of the insufficiencies of the old system may be, even if somewhat brutally, overcome, in the long-term this implosion carried a major threat to the future competitiveness of those economies, as the long transition process in those countries over the last 15 years illustrated.

Section 3: The rise and fall of industrial R&D

Behind the international attempt on measuring most and foremost research and experimental development in the Frascati Manual was a recognition that most efforts to generate discoveries and inventions had become centred in relatively specialised private and public institutions in the "Research and Experimental Development" Network. While the wider spectrum of scientific and technological services (STS) which linked the R&D system with production and other technical activities were considered essential for efficient innovation and often predominated in the diffusion of technical change in many branches of industry, it was the professional R&D laboratory and the activities carried out there which were the characteristic of the industrial S&T system as it had emerged over the late 19th and 20th Century. Although government and university laboratories had existed earlier, it was only in the 1870s that the first specialised R&D laboratories were established in industry.

The professional R&D system was barely recognised at all by economists, despite their recognition that "something" (a residual, a measure of our ignorance) was behind most of the economic growth in the 20th Century and the post-war period in particular. But, of course, long before the 20th Century, experimental development work on new or improved products and processes was carried out in ordinary workshops[3]. However, what became distinctive about modern, industrial R&D and justified the focus in the Frascati Manual on this concept was its scale, its scientific content and the extent of its professional specialisation. A much greater part of technological progress appeared attributable to research and development work performed in specialised laboratories or pilot plants by full-time qualified staff. It was this sort of work which one wanted to get officially recorded in R&D statistics. It was totally impracticable to measure the part-time and amateur inventive work typical of the nineteenth century. In short, present R&D statistics are really a measure of the professionalisation of this activity.

Much of the subsequent research at SPRU, at Yale and other places, highlighted the fact that the extent of such R&D specialisation and professionalisation should not be exaggerated. Important inventions were still made by production engineers or private inventors. With every new process, many improvements are made by those who actually operate it. In some firms there are "Technical" or "Engineering" departments or "OR" sections, whose function is often intermediate between R&D and Production and who often contribute far more to the technical improvement of an existing process than the formal R&D department, more narrowly defined. But even viewed in retrospect, the focus on R&D seemed justified. It was the specialisation of the R&D function which justified such expressions as the "research revolution" to describe what happened in twentieth-century industry, industry associations of R&D managers were

[3] As we noted elsewhere: "The classical economists were well aware of the critical role of R&D in economic progress even though they used a different terminology. Adam Smith (1776) observed that improvements in machinery came both from the manufacturers and users of machines and from "philosophers or men of speculation, whose trade is not to do anything but to observe everything". Although he had already noted the importance of "natural philosophers" (the expression "scientist" only came into use in the nineteenth century), in his day the advance of technology was largely due to the inventiveness of people working directly in the production process or immediately associated with it: "a great part of the machines made use of in those manufactures in which labour is most subdivided, were originally the inventions of common workmen" (Smith, 1776, p. 8). Technical progress was rapid but the techniques were such that experience and mechanical ingenuity enabled many improvements to be made as a result of direct observation and small-scale experiment. Most of the patents in this period were taken out by "mechanics" or "engineers", who did their own "development" work alongside production or privately." This type of inventive work still continues today and it is essential to remember that it is hard to capture it in official R&D statistics (Freeman and Soete 1997, p. 7-9).

created in different countries, and many large firms in the industrial countries had set up their own full-time specialised R&D sections or departments.

The "research revolution" was not just a question of change in scale, it also involved a fundamental change in the relationship between society and technology. The very use of the word "technology" usually carries the implication of a change in the way in which knowledge about productive techniques is organised. If "technology" simply meant that body of knowledge which relates to the production or acquisition of food, clothing, shelter and other human needs, then of course all human societies have used technology. It is perhaps the main characteristic which distinguished humanity from other forms of animal life. But until recently, knowledge of these "arts and crafts", as they used to be called, was largely based on skills of hand and eye, or on practical experience which was transmitted from generation to generation, by some sort of apprenticeship or "learning by doing"[4].

The expression "technology", with its connotation of a more formal and systematic body of learning, only came into general use when the techniques of production reached a stage of complexity where these traditional methods no longer sufficed. The older arts and crafts (or more primitive technologies) continued to exist side by side with the new "technology" and it would have been ridiculous to suggest that modern industry would now entirely be a matter of science rather than craft. Nevertheless, there was an extremely important change in the way in which knowledge of the techniques used in producing, distributing and transporting goods was ordered. Some people call this change simply "technology", to distinguish those branches of industry which depend on more formal scientific techniques than the older crafts. However, in many cases very sophisticated industries are also using craft techniques and vice-versa. Consequently, the division of industries into "high", "medium", or "low" technology categories is usually based on a measure of R&D-intensity, rather than an examination of process technology and can hence only be a very rough description.

This change can also be seen from the patent statistics for the various branches of industry. In mechanical engineering, applications from private individuals are still important by comparison with corporate patents, but in electronics and chemicals they are very few. The overall share has been declining since 1900 and reflects the increasingly scientific content of technology. Indeed, in some areas, such as bio-technology it is hard to distinguish what is science and what is technology.

As shown in Graph 1 the concept of R&D while somewhat on the decline (at least over the short period considered here) seems to correlate remarkably well with the concept of productivity, highlighting to some extent the implicit close correlation between the two concepts as assumed in many economic models where R&D investments have often been considered the measure of technological progress. We would argue that it neatly illustrates the particular contribution the community of S&T indicators analysts and policy makers, whether located in statistical offices, universities, government departments or other research institutes, have made to both the economic policy and academic community over the last forty years.

[4] One of the first economists to discuss technical change already in the 17th Century was Sir William Petty. He referred to inventions and innovations as "facilitations of art" (Petty 1691, p. 118).

Section 4: From R&D to the *blue sky* of innovation

The dissatisfaction with R&D as an "industrial research and experimental development" input indicator was not confined, however, to the omitted role of engineering, design and other STS activities. Following the early SPRU and Yale innovation surveys it became clear that the actual industrial locus of innovation could well be far upstream or downstream from the firm or sector having carried out the research. Some of our closest colleagues, such as the late Keith Pavitt (1984), Roy Rothwell (1977) and Jo Townsend (1976) had been at pains for many years to stress the much more complex sectoral origin and nature of innovation, than the one being assumed through the simple but popular technological classification of industries into high, medium and low R&D intensity. There is by now a large literature on the importance of sectoral classifications for STI indicators which we will not discuss here[5].

Such dissatisfaction with R&D indicators was at the basis though of the successful development of a new set of STI output indicators within the framework of the Oslo manual (1992) and the different surveys "waves" being carried out since then most notably by Stats Canada and the EC, under the joint initiative of the OECD and Eurostat. As was discussed at the first Blue Sky Conference ten years ago in Paris, and will be discussed at length in the different contributions presented here at the Blue Sky II Forum, these surveys have opened in the true spirit of the Blue Sky concept, many new avenues "without limiting horizons" of new micro-based evidence research on STI indicators, bringing to the forefront new insights not only into the nature and origin of technological but also into what has become known as non-technological innovations.

Again it is impossible in these few pages to do justice in any sense to the innumerable academic research papers, PhDs, policy papers which have been written on such innovation survey data and innovation indicators. However, Graph 2 might, as in the case of Graph 1, provide a hint at the impact of the broadening of STI in the direction of innovation on the larger economic policy community. As Graph 2, suggests the concept of innovation is today not just more popular than the one of R&D, it is also closely associated with the concept of GDP, exactly as was R&D with productivity. In short, compared to Graph 1, Graph 2 tends to suggest that having broadened STI indicators from R&D to the "blue sky of innovation", we seem to have come even closer to the measurement of economic dynamics.

As in the case of the development of harmonized industrial R&D statistics within the Frascati manual, we would claim that the development of harmonized, innovation output indicators within the framework of the Oslo manual, was a central factor behind both a better understanding of the science and technology system[6] and the changing nature of the innovation process itself as emphasized by many of our colleagues in the 90's[7]. According to David and Foray (1995), innovation capability became now seen less in terms of the ability to discover new technological principles, but more in terms of the ability to exploit systematically the effects produced by new combinations and use of pieces in the existing stock of knowledge. Not surprisingly the new model appears closely associated with the emergence of various new sorts of knowledge "service" activities, implying to some extent, and in contrast to the Frascati R&D focus, much more **routine** use of a technological base

[5] See Malerba (2004) for an overview of recent work in this area.
[6] As in the form of postmodern science (Funtowicz and Ravetz (1993, 1999), strategic science (Rip 2002) or co-produced science (Callon 1999).
[7] At the risk of omitting some, one may think of Gibbons (1994), David (1996), Lundvall (1994), Foray (1998), Edquist (1998) and many others.

allowing for innovation without the need for particular leaps in science and technology, something which has also been referred to as “innovation without research” (Cowan and Van de Paal 2000, p. 3).

One could argue that this model brings back to the forefront the particular importance of STS activities as it puts now a much stronger emphasis on access to state-of-the-art technologies. While fuelled so to say by Internet and broadband, this mode of knowledge generation, based in David and Foray’s (1995, p. 32) words “on the recombination and re-use of known practices” raises now, however, and in contrast to the early Frascati years, much more information-search problems as it is becoming confronted with impediments to accessing the existing stock of information that are created by intellectual property right laws.

Not surprisingly at the organisational level, the shift in the nature of the innovation process implies some fundamental shifts in the traditional locus of knowledge production, such as the professional R&D lab. The old industrial system was based on a relatively simple dichotomy between knowledge generation and learning in professional R&D laboratories, engineering and design activities, of which only the first part were measured through Frascati and production and distribution activities where basic economic principles would prevail of minimizing input costs and maximizing sales. It is likely to be still very much dominant in many industrial sectors ranging from chemicals to motor vehicles, semiconductors and electronic consumer goods where technological improvements at the knowledge generation end appear still today to proceed along clear agreed-upon criteria and a continuous ability to evaluate progress. As in the old industrial model the largest part of the engineering research consists still here of the ability to hold in place (as Richard Nelson would put it): to replicate at a larger industrial scale and to imitate experiments carried out in the research laboratory environment.

The more recent mode of technological progress is more associated with knowledge service activities with as extreme examples the continuous attempts at ICT-based efficiency improvements in e.g. the financial and insurance sectors, the wholesale and retail sectors, health, education, government services, business management and administration. It is more based on flexibility and confronted with the intrinsic difficulties in replication. Learning from previous experiences or from other sectors is difficult and sometimes even misleading. Evaluation is difficult because of changing external environments: over time, among sectors, across locations. It will often be impossible to separate out specific context variables from real causes and effects. Technological progress will in other words be more of the trial and error base yet without, as in the life sciences providing “hard” data which can be scientifically analysed and interpreted. The result is that technological progress will be less predictable, more uncertain and ultimately more closely associated with entrepreneurial risk taking.

If the first shift in our understanding of innovation involved removing the dichotomy between R&D and production, the second shift has actually removed (partially) the distinction between production – as a locus for innovation – and consumption. The notion of user-driven innovation, originally already developed by innovation scholars such as Lundvall and his group in Aalborg in the late 70’s, has now taken on much more importance and been used to explain amongst others the rise of open source software as well as some other sectors such as sports equipment by Von Hippel (2004). Such innovation reduces risks for individual entrepreneurs, as the risk of developing an unsuccessful technology is spread across the many user-producers who contribute and perhaps implement their own ideas.

Conclusions: "*Recherche sans frontières*": national statistics measuring global impacts

Economically, the world has witnessed an unparalleled growth and transformation over the last forty years. Economic development has undoubtedly been spurred by the opening up and ensuing expansion of world trade and the dramatic reduction in barriers to capital movements, but it would only be fair to say that either in conjunction with such liberalisation or separate from it, the growth externalities of knowledge have had undoubtedly a lot to do with the rapid post war growth of the OECD countries. First under the form of a technological and consumption catching up of the European countries and Japan – the thirty glorious years ("les trente glorieuses" as Keith Pavitt was frequently keen to quote Jean Fourastié) – and subsequently of the newly industrialising South East Asian economies. The third phase set in motion in the late 90's with the world integration of the large emerging economies such as Brazil, Russia, India and China (the BRICs) – compared by Richard Freeman with a doubling of the world labour force – could be said to be still in full swing requiring a much longer period of global adjustment of another thirty years.

STI indicators play today in interaction with these shifts in global demand a crucial role in national policy debates about science, technology and innovation. There is little doubt that the largest part of world wide growth and development over the last ten years has been associated with an acceleration in the diffusion of technological change and world wide access to codified knowledge. The role of information and communication technologies has been instrumental here as has been that of more capital and organisational embedded forms of technology transfer such as foreign direct investment which is today as a percentage of GDP a decimal point greater than what it was forty years ago and no longer limited to the OECD world. There remains of course a huge world-wide concentration of R&D investment in a number of rich OECD countries, but it is important, certainly form a national STI policy perspective, to realize that such activities, whether privately or publicly funded are increasingly becoming global in focus: "*research without frontiers*".

Contrary to national policy belief, typified e.g. by the original emphasis in the EU on the so-called Barcelona 3% R&D investment norm to be achieved by 2010 by EU member states, private firms who were supposed to contribute most (2%) to the attainment of this norm, are not interested in increasing R&D expenditures just for the sake of it but because they expect new production technology concepts, new products responding to market needs, to improve their own efficiency or strengthen their global competitiveness. Given the much higher risks involved in developing such new products for global markets, firms today will often prefer to license such technologies or alternatively outsource the most risky parts to small high tech companies which operate at arms length but can be taken over, once successful. Not surprisingly in most OECD countries, the large R&D intensive firms appear today less interested in increasing their R&D investments in OECD countries than in rationalising them or where possible reducing the risks involved in carrying out R&D by collaboration with others sometimes through publicly sponsored or enabled programmes (SEMATEC and IMEC in micro- and today nano-electronics), or through so-called open innovation collaboration.

Not surprisingly many small, traditionally high R&D intensive OECD countries have witnessed declines in their privately funded R&D intensity over the last years with little or no relationship to their economic performance. The central question, as was already analysed in the 90's for the OECD by input-output economists such as Mohnen (1994), appears to be whether the benefits of knowledge investments can be appropriated domestically or will "leak away" globally. In the catching-up growth literature (Fagerberg 1991, Verspagen 1991), it was emphasized how this phenomenon would be characterized by lagging countries benefiting from the import, transfer of technology and knowledge, formally and particularly informally. As a logical extension, in the current global world economy, it seems obvious that increasing R&D investment is unlikely to benefit only the domestic economy. This holds *a forteriori* for small countries, but is increasingly valid for most countries with only a couple of exceptions left. Thus, as Meister and Verspagen (2003) calculated, achieving the 3% Barcelona target in the EU by 2010 would ultimately not reduce the income gap between the EU and the US, the benefits of the increased R&D efforts not only accruing to Europe but also to the US and the rest of the world. In a similar vein, Griffith, Harrison and Van Reenen (2004) illustrated how the US R&D boom of the 90's had major benefits for the UK economy and in particular for UK firms having shifted their R&D to the US. A UK firm e.g. shifting 10% of its R&D activity to the US from the UK while keeping its overall R&D expenditures at the same level, would witness an additional increase in productivity of about 3%, an effect which appeared to be of the same order of magnitude "as that of a doubling in its R&D stock" (Griffith, Harrison and Van Reenen 2004, p.25). In short the link between the location of "national" firms' private R&D activities and national productivity gains appears today increasingly tenuous.

It is here, we would claim that the broadening of the STI concept to include "innovation" with its much stronger local links towards growth and development dynamics is particularly insightful, and contains significant new policy insights. From a global growth and development perspective, it is indeed no longer the impact of the transfer of industrial technologies on economic development which should be at the centre of the debate but rather the broader organisational, economic and social embedding of such technologies in a development environment and the way they unleash or block particular specific development and growth opportunities. That process is in all likelihood much more complex in a developing country context than in a developed country one. As has become recognized in the endogenous growth literature [8], the innovation policy challenge with its characteristic Schumpeter mark 1 versus mark 2 features appears closely associated with levels of development. In the high income, developed country context the innovation policy challenge seems increasingly directed towards questions about the sustainability of processes of "creative destruction" within environments that give increasingly premiums to insiders, to security and risk aversion, and to the maintenance of income and wealth. In an emerging, developing country context, by contrast, the challenge appears directed towards the more traditional, "backing winners", industrial science and technology policies bringing also to the forefront the importance of engineering and design skills and accumulating "experience" in particular. Finally, there are the majority of developing countries characterized by "disarticulated" knowledge systems, well described by many development economists in the area of science and technology (Martin Bell 1994, Francisco Sagasti 2005) and where the endogenous innovation policy challenge is most complex of all and which time nor space allows us to address here.

The science-technology-innovation system is one that is continuously and rapidly evolving. As we have tried to show, frontiers and characteristics that were important last century may no longer be so relevant today and indeed may even be positively misleading. The sky of STI indicators is indeed without horizons.

[8] This view of the philosophy and aims of innovation policies differing amongst countries according to their level of development, reminiscent of many of the arguments of the old infant industry type arguments has now become popular in the endogenous growth literature. See Aghion and Durlauf (2005).

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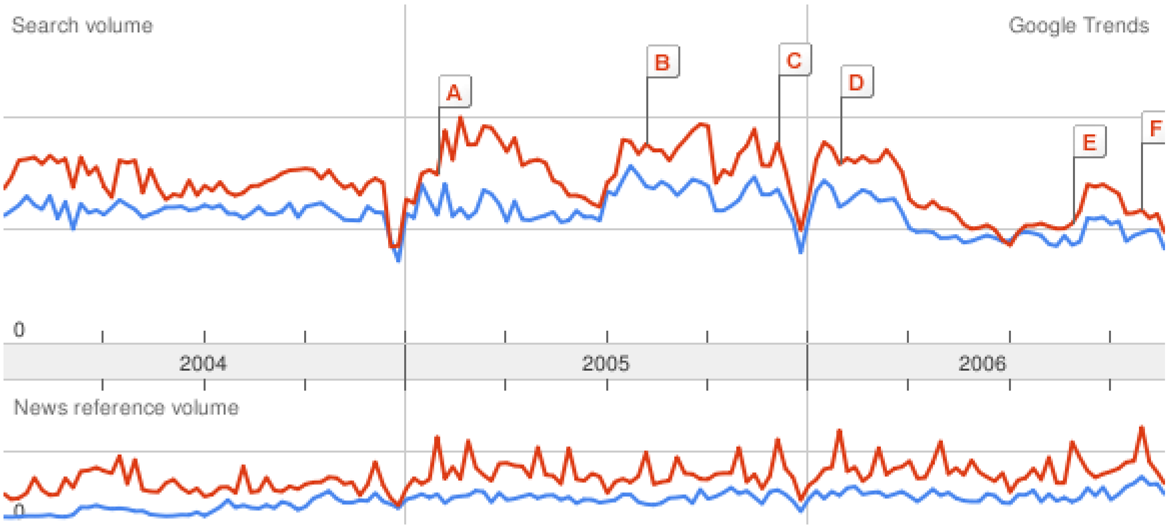
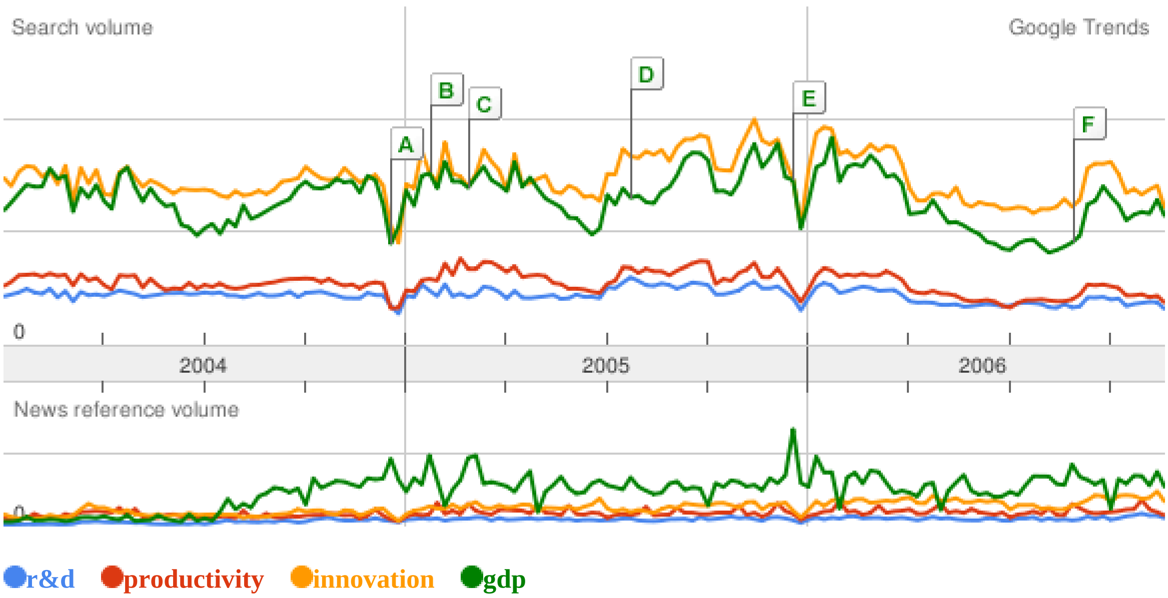
Graph 1: R&D and Productivity in Google Trends (January 1st, 2007)



Graph 2: GDP, Innovation and R&D, productivity in Google Trends



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